TÜBİTAK

Turkish Journal of Agriculture and Forestry

http://journals.tubitak.gov.tr/agriculture/

Research Article

Turk J Agric For
(2017) 41: 452-462

doi:10.3906/tar-1705-8

Chemical composition and morphometric traits and yield of carrots grown in organic and integrated farming systems

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Received: 02.05.2017 • **Accepted/Published Online:** 05.09.2017 • **Final Version:** 18.12.2017

Abstract: Changes in chemical composition and quality traits of carrot roots (*Daucus carota* L.) grown in organic (ORG) and integrated (INT) farming systems were investigated during two successive years. Three carrot cultivars (Fanal, Rodelika, and Rolanka) were included. Determinations of sugars, organic acids, α- and β-carotene, and vitamin C were performed with an HPLC system, and a liquid chromatography-mass spectrometry (LC-MS) system was used for the identification and quantification of phenolics. A higher yield of carrot in the ORG system was observed (42–44 t ha^{-1}) as compared with the INT system (37–40 t ha^{-1}). The impact of farming system on morphometric traits was cultivar-specific. The composition of sugars and carotenes was determined using compositional data analysis. The relative amount of sucrose against the combined amount of fructose and glucose was higher for roots from the ORG system compared to the INT system and for roots of Rodelika compared to Fanal. Roots from ORG farming contained 1.6-fold higher content of malic acid in Fanal and Rolanka and 2.4-fold in Rodelika compared to the INT system. Organic farming increased the content of vitamin C by 5% in roots of Rodelika, 15% in roots of Rolanka, and 22% in roots of Fanal compared to the INT farming. Changes in carotenes content in carrot roots were cultivar-specific with significantly higher α- and β-carotene contents in Rodelika and Rolanka compared to Fanal. Farming system influenced the ratio of β-car/α-car, which was higher for roots gathered from the INT system (1.9) compared to ORG system (1.7), but the differences were not significant. Phenolic acids detected in the study differed significantly in relation to cultivar as revealed by lower concentrations in the roots of Rodelika and Fanal compared with higher levels in the roots of Rolanka.

Key words: *Daucus carota* L., cultivars, integrated farming, organic farming, phenolic acid, carotenoid, sugar and acid components

1. Introduction

Integrated and organic farming systems are alternative farming methods developed to reduce the environmental and human health impacts of conventional farming systems (http://www.mkgp.gov.si/en/). The integrated system aims to minimize the use of technical means normally adopted by conventional agriculture. Chemical fertilizers are thus applied in doses and times and with distribution techniques that take into account the real needs of crops and weed, pest, and disease control strategies based on integrated pest management are performed (Eur-Lex, 2014). Integrated farming uses techniques such as integrated pest management of balanced nutrient supply and improved conventional agriculture to such an extent that it may appear unnecessary to strictly ban pesticides and mineral fertilizers as required by organic standards (Phatak, 1992). The organic farming system relies on crop rotations, crop residues, animal manures, off-farm organic wastes, mechanical cultivation, mineral-bearing rocks, and aspects of biological pest control to maintain the soil and its tillage, to supply plant nutrients, and to control insects and weeds (Reganold and Wachter, 2016) and exclude the use of inorganic fertilizer and synthetic pesticides (Soltoft et al., 2010). In recent years, organic farming has gained popularity due to an increase in consumer demand for organically grown foods and the desire of growers to sustain and improve the soil (Dimitri and Oberholtzer, 2009). An advantage of the organic farming system is

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increased organic matter levels in soil, which beneficially affects the aggregation of soil particles (Mader et al., 2002). On the other hand, with an integrated farming system, the application of mineral fertilizer can compensate for less desirable soil conditions such as insufficient soil organic matter (Rosen and Allan, 2007). In previous reviews, data about the impact of the growing system on yield and quality have shown conflicting results (Bourn and Prescott, 2002; Rosen and Allan, 2007). Supporters of organic agriculture claim that organically grown food contains more phytonutrients, which contribute to the natural defense ability of plants, compared to conventionally grown food, which lose their natural resistance due to the use of synthetic fertilizers and pesticides. Opponents of organic farming, on the other hand, claim that organically grown vegetables contain fewer phytonutrients due to the poorer availability of nutrients, although they contain more defensive secondary metabolites, which can be harmful to health in large amounts (Brandt and Molgaard, 2001). In an organic farming system, plants are often exposed to infections and pests that cannot be suppressed efficiently due to the poor offerings of approved pest control products (Maggio et al., 2013). The abovementioned stress conditions affect the production of polyphenolic compounds, especially flavonoids and phenolic acids, which in small amounts have been proven to have a beneficial effect on humans (Mizrahi et al., 2009).

Carrot (*Daucus carota* L.) is an important root vegetable, the consumption of which, both fresh and processed, has tended to increase (Gajewski et al., 2009), mostly due to the simple cultivation technology, excellent storage properties, wide range of culinary uses, and numerous health benefits (Goncalves et al., 2010). The main components of raw carrots are soluble sugars, which contribute the largest part of the dry substance (Suojala, 2000), and carotenoids, which determine carrots' typical color (Smolen and Sady, 2009). Phenolic compounds contribute to sensory properties such as color, flavor, and bitterness (Goncalves et al., 2010). Despite the presence of some reports available on metabolite synthesis (Zhang and Hamauzu, 2004; Taylor and Ramsay, 2005; Stange et al., 2008) and the impact of genotype (Nicolle et al., 2004; Karkleliene et al., 2012), environmental factors (Chugahuja et al., 1993; Suojala, 2000), growth stages, and morphological structures (Wang et al., 2015), as well as technological measures (Soltoft et al., 2010; Paoletti et al. 2012; Singh et al., 2012), few details are known about changes in the chemical profile of carrot taproots, especially in relation to the effects of the farming system as a whole.

The aim of this study was therefore to evaluate the effects of organic and integrated farming systems as a whole on the chemical composition and some morphological traits of carrot taproots of three carrot cultivars. Phenolic acids, carotenoids, sugar, and acid components were evaluated and compositional data analysis was carried out in order to determine the composition of sugars and carotenoids.

2. Materials and methods

2.1. Experiment

Carrot taproots were collected in 2011 and 2012 from two experiments, which were conducted from May to September in two successive years, in the experimental field of the Biotechnical Centre Naklo in Strahinj, Slovenia (46°17′N, 14°18′E; 422.6 m a.s.l.), on which production of vegetables has been carried out under certified organic and integrated management for more than 10 years. Measures in the integrated farming system were taken in accordance with integrated pest management guidelines (Eur-Lex, 2014). Organic production was managed according to European Union Council Regulation (EC) No. 834 (Eur-Lex, 2007). Basic soil characteristics, sowing and harvesting dates, fertilizer applications (source, type, fertilizer in g m^{-2}, and nutrient amount in kg ha^{-1}), and plant protection measures are presented in detail in Table 1. In both years, three carrot varieties (Fanal, Rodelika, and Rolanka) were cultivated in two farming systems (organic and integrated). Fanal is a variety with a long and blunted shape, smooth skin, and a sweet-tasting taproot, with an intensive red color and small, uniformly colored phloem tissue. Its growing period is around 140 days. Rodelika is a variety bred from the variety Rothild and has a long, blunted, and smooth-skinned taproot with an intensive red color and a sweet, aromatic taste. It is very good for storage and industrial cultivation. The growing period is 140–150 days. Rolanka is a variety with medium to long smooth-skinned taproot, a cylindrical shape compared to Rodelika, and a more rounded shoulder and even deep-orange exterior color throughout the taproot with a sweet, aromatic taste. The growing period is 140–160 days (Reinsaat, 2016). Organic seeds were used for the experiments, so the requirement of the organic farming system on using seeds of organic origin was met (Eur-Lex, 2007). Soil chemical analysis, which was performed 14 days before the sowing date in 2011 and 2012, showed much higher levels of P and K and also higher organic matter levels in plots on which the organic farming system had been applied in comparison with the soil under integrated farming cultivation. Nitrate nitrogen was analyzed three times per year (before the sowing date, in the middle of the growing period, and immediately after the yield was harvested) (Table 1). The soil conditions of organic plots were mostly a consequence of frequent application of organic manure, required for the organic farming method, while in soil on which the integrated system was applied, organic manure was applied every 3 years, in relation to

Table 1. List and description of the experimental work related to the experiments in the years 2011 and 2012.

	Field for organic farming system				Field for integrated farming system and control plots			
Soil description	Silty loam				Sandy loam			
Soil texture								
Soil NO_3-N (mg kg^{-1})	#6.8* / 7.2** / 7.8***				3.7 / 4.8 / 4.1			
Soil P_{Olsen} (mg/100 g)	34.8				11.6			
Soil K_{exch} (mg/100 g	23.8				14.9			
Organic matter (g/kg)	77.3				23.0			
Sowing date	In 2011 / 2012	7 May / 3 May			7 May / 3 May			
Fertilization	Type of fertilizer	N:P:K	g fertilizer m^{-2}	N:P:K (kg ha^{-1})	Type of fertilizer	N:P:K	g fertilizer m^{-2}	N:P:K (kg ha^{-1})
	Organo Agroruše	3:3:3	150	45:45:45	Compo Novatec	14:7:17	120	168:84:204
Plant protection	Cvetal Algin (1%)		1.0% (preventive use) 2.0% (preventive use)		Score 250 EC Bulldock EC 25	Fungicides Insecticides	0.15% 0.03%	
	Cvetal horsetail extract		40 g m^{-2}					
	Algoplasmin Super-F (Unichem, SI)		0.5% (fungicides)					
	Aktiva (Unichem, SI)		1.0% (insecticides)					
Harvest date	In 2011 / 2012		26 / 22 September (141 days after sowing (DAS))					

- analysis of NO_3-N in the soil was done: * - before the sowing date; ** - in the middle of the growing season; *** - after the yield was harvested.

a three-course crop rotation. In view of the fact that less desirable soil conditions can apparently be compensated by the application of mineral fertilization (Rosen and Allan, 2007), higher amounts of nutrients were applied in integrated treatments than in organic treatments in order to achieve a similar yield.

2.2. Sampling and measurements

In both years, seeds were sown on raised beds at a plant density of 0.2 m × 0.05 m (plant density 1,000,000 plants ha^{-1}) at the beginning of May. The carrot taproots were harvested at the beginning of September. Immediately after harvesting, six carrot samples were randomly collected from the three middle plot rows and transported to the laboratory for further morphological and chemical analysis. The lengths of the taproots were measured and weighed on high-precision Kern EW 600-2M scales; the shoulder of the crown was measured in diameter and in the width of the xylem and root diameter, using a Powerfix Profi Electronic Vernier Caliper, and the phloem/xylem ratio was calculated. Marketable carrot yield (UNECE Standard FFV-10) was measured and expressed in t ha^{-1}.

The extraction of individual carotenoids, vitamin C, individual sugars, and organic acids, as well as individual phenolic compounds, was performed immediately after morphological measurements to prevent pigment degradation.

2.3. Weather conditions

Meteorological data for the growing periods of the experiments conducted in 2011 and 2012 were taken from the Brnik meteorological station in Slovenia (363 m a.s.l.; 46°13′28″N, 14°27′21″E), which is 12.37 km (air distance) from the experimental field. The average air temperature in the research area for the 1981–2011 reference period was 16.8 °C and the mean annual precipitation was 1363 mm, measured at the same meteorological station. During the growing period, mean air temperatures were above the 30-year average by 1.38 °C in 2011 and 1.62 °C in 2012, with the greatest increase in September 2011 of 3.2 °C and August 2012 of 2.6 °C. Precipitation was below the 30-year average, with the greatest shortfall in September 2011 (49% below average) and in July 2012 (43% below average), while precipitation in July 2011 and in September 2012 were 20% above the 30-year average.

2.4. Chemicals

The following standards were used for quantification of sugars, organic acids, carotenoids, and phenolic compounds: Fluka Chemie (Buch, Switzerland): glucose, fructose, sucrose, citric acid, *p*-coumaric acid; Sigma-Aldrich (Steinheim, Germany): pyruvic, fumaric, ascorbic and chlorogenic acids (5-caffeoylquinic acid), α-carotene, and β-carotene; Roth (Karlsruhe, Germany): malic and ferulic acid. Methanol for the extraction of phenolics was acquired from Sigma-Aldrich. For the individual carotenoid analyses, ethanol, hexane, and sodium chloride were purchased from Sigma-Aldrich. In the mobile phase for determination of carotenes, ammonium acetate was purchased from Fluka Chemie. Formic acid and HPLC-MS grade acetonitrile from Fluka Chemie were used for

the mobile phase. The water used in sample preparation, solutions, and analysis was bidistilled and purified with the Milli-Q Millipore Direct 8 system (Merck Millipore, Billerica, MA, USA).

2.5. Extraction and HPLC analysis of carotenoids

Carotenoid extraction was conducted according to the method previously described by Wright and Kader (1997). Briefly, 1 g of finely grated carrot was added to round-bottomed centrifuge tubes, which were wrapped with aluminum foil to prevent light access; 0.1 g of $MgCO_3$ was added to neutralize the acids and homogenized with 5 mL of cold ethanol for 2 min using a T-25 Ultra-Turrax, (IKA Labortechnik, Staufen, Germany) at 8500 rpm. Eight milliliters of hexane was added and the sample was homogenized again for 2 min at 8500 rpm. The homogenate in tubes was then centrifuged for 4 min at 9000 rpm and 4 °C (Eppendorf Centrifuge 5801R, Hamburg, Germany). The hexane layer was transferred to a Büchi flask with a pipette, flushed with nitrogen, sealed, and kept in the dark. Five milliliters of saturated NaCl was added to the contents of the centrifuge tube and stirred gently until homogenized, after which another 8 mL of hexane was added to the mixture and homogenized for 2 min with the Ultra-Turrax at 4000 rpm. The steps of tube centrifugation and hexane layer separation were repeated three more times (until the colorless phase of hexane appeared), with the extract added each time to the previously collected one. During the extraction phase, dimmed light conditions were applied. The combined hexane extracts were evaporated to dryness in a rotary evaporator at a temperature never exceeding 25 °C. The solid phase of extract was dissolved in 4 mL of petroleum ether and filtered through a 0.20-µm polyamide Chromafil AO-20/25 filter (Macherey-Nagel, Düren, Germany) into an amber vial.

High-performance liquid chromatography (HPLC) analysis was based on the method described by Rodriguez-Amaya (2010). For analysis of individual carotenoids, the Thermo Finnigan Surveyor HPLC system (San Jose, CA, USA) was used, with the diode array detector at 450 nm. The elution solvent was a methanolic solution of ammonium acetate (3.84 g L^{-1}) (A) and 100% acetonitrile (B). The samples were eluted according to a linear gradient: 5% B (0–25 min), 50% B (25–26 min), 100% B (25–36 min). The injection amount was 20 µL and the flow rate was 1.5 mL min^{-1}. The Phenomenex Gemini C18 column (Phenomenex, Torrance, CA, USA) was maintained at 24 °C. The compounds were established by comparing retention times and UV spectral features of individual compounds, as well as by adding an external standard. All compounds were identified by HPLC-MS (Thermo-Scientific, LCQ Deca XP MAX) with an electrospray interface (ESI) based on positive ion mode. The analyses were carried out using full-scan data-dependent MS^n scanning from *m/z* 160 to 1250. Identical conditions and solvents were used for both HPLC analyses.

2.6. Extraction and analysis of sugars and organic acids

The carrot taproot was finely chopped and 10 g of fresh weight was immersed in 50 mL of double-distilled water and homogenized with the T-25 Ultra Turrax (IKA Labortechnik) for 1 min at 9000 rpm. The samples were left for 30 min at room temperature, with frequent stirring. The extracted samples were centrifuged at 10,000 rpm for 6 min at 4 °C (Eppendorf Centrifuge 5801R, Hamburg, Germany). Supernatant was filtered through a polyamide Chromafil A-20/25 filter (Macherey-Nagel) into vials and analyzed according to the method described by Mikulic-Petkovsek et al. (2007) using HPLC (Finnigan Spectra System, Thermo Scientific, Waltham, MA, USA). The method of external standards was applied to calculate the concentration of organic acids and sugars, which was then presented in g kg^{-1} of fresh weight.

2.7. Extraction and analysis of ascorbic acid

Carrot roots were chopped with a ceramic knife into small pieces and 2.5 g of the fresh weight was immediately immersed in 5 mL of 2% metaphosphoric acid and ground thoroughly in a ceramic mortar. The samples were left for extraction on a shaker for 30 min at room temperature and centrifuged at 10,000 rpm for 5 min at 4 °C (Eppendorf Centrifuge 5801R). The supernatant was filtered through cellulose Chromafil A-20/25 filters (Macherey-Nagel), poured into a vial, and analyzed using HPLC (Thermo Scientific Finnigan Spectra System) as previously reported by Mikulic-Petkovsek et al. (2012). The concentrations of ascorbic acid were calculated with the help of the corresponding external standard and expressed in mg kg^{-1} fresh weight (FW).

2.8. Extraction and analysis of phenolic compounds

Extraction of phenolic compounds was carried out according to Mikulic-Petkovsek et al. (2012) with some modifications. Eight grams of finely chopped carrot roots was immersed in 10 mL of extraction solution (methanol containing 1% (w/v) 2.6-di-tert-butyl-4-methylphenol (BTH) and 3% (v/v) formic acid) and extracted for 60 min in an ultrasonic ice bath. Samples were then centrifuged for 7 min at 9000 rpm. The supernatant was filtered through a 0.20-µm polyamide Cromafil AO-20/25 filter (Macherey-Nagel), transferred to a vial, and injected into the HPLC system. Phenolic compounds were analyzed on the Thermo Finnigan Surveyer HPLC system (Thermo Scientific) with a diode array detector (DAD) at 280 nm (hydroxycinnamic acid derivatives) according to the chromatographic condition as was previously described in the study by Mikulic-Petkovsek et al. (2012).

All phenolic compounds were identified by an HPLC-Finnigan MS detector and an LCQ Deca XP MAX

instrument (Thermo Finnigan, San Jose, CA, USA) with ESI operating in negative ion mode. The analysis was carried out using full-scan data-dependent MS^2 scanning from *m/z* 115 to 800 and the concentrations of phenolic compounds were calculated from peak areas of the sample and corresponding standards and expressed in mg kg^{-1} fresh weight (FW).

2.9. Statistical analysis

Experiments were treated as split-plot design two-factorial experiments in four randomized replications. Since the results obtained in two successive years of research were comparable, they were recorded as mean values of a 2-year study. In both years, the main factor, 'farming system', had two variables, organic farming (ORG) and integrated farming (INT); the second factor (subfactor), 'variety', had three variables (Fanal, Rodelika, Rolanka). The data were analyzed using a general linear model (GLM) procedure. Contrasts were performed to determine significant differences between means where necessary. The average structure of sugars and carotenoids was analyzed using compositional data analysis (Pawlowsky-Glahn and Buccianti, 2011), since the sugars were treated as a composition of three components (fructose, glucose, and sucrose) and carotenoids as a composition of two components (α- and β-carotene). The relative response of each to the other was also analyzed using isometric log ratio transformation, with a balanced partition of components. Two *ilr* coordinates were considered, the first (*ilr1*) expressing relative amounts of fructose against glucose and β-carotene against *α*-carotene and the second (*ilr2*) the relative amount of sucrose against the geometrical mean of fructose and glucose. GLM was used to analyze the impact of farming system and variety, their interactions with those two *ilr* coordinates. Statistical analysis of the data was performed using RCommander 2.13.1 (RDC Team, 2011).

3. Results

Average values for yield in both years and visible traits of three carrot varieties, which were grown in ORG and INT systems, are presented in Figure 1 and Table 2. For the carrot yield, ANOVA showed a significant impact of tested farming systems. Yield from the ORG system was higher with all three varieties than the yield from the INT system, although the differences were significant only for Rodelika and Rolanka.

Changes in all measured morphological characteristics of carrots, except the phloem/xylem ratio, were found to be genetically dependent and influenced by ORG and INT systems (Table 2). With the variety Fanal, the ORG system significantly increased the values of all measured traits compared to the INT system. With Rodelika and Rolanka, only aboveground weight was affected significantly by the farming system, reflected in increased aboveground weight in the INT system compared to the ORG system.

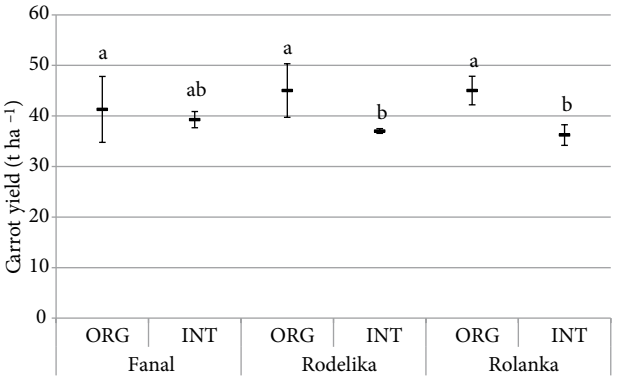

Figure 1. The average yield (t ha^{-1}) of three carrot varieties (Fanal, Rodelika, and Rolanka) selected from organic (ORG) and integrated (INT) farming systems in two growing seasons (in 2011 and 2012). Values are shown as mean ± SD. Different letters denote significantly differences (Duncan test, $P < 0.05$) between farming systems (ORG and INT).

Cultivar significantly affected glucose and fructose, while for sucrose and total sugar content, the effect of cultivar was marginally statistically significant ($P = 0.0522$), but farming system had no significant impact on sugar components (Table 3). The relative content of sugar components was analyzed using an isometric log ratio transformation of the three-part sugar composition, giving two *ilr* coordinates. Genotypic effect was revealed in greater ilr_1 for roots of Fanal compared to the other two cultivars. The relative amount of sucrose against the combined amount of fructose and glucose (ilr_2) was higher for carrots from the ORG system compared the INT system and higher for samples of Rolanka compared to Fanal (Table 3).

Four organic acids were detected in the carrot roots: malic acid was the major one and pyruvic was the second most prevalent, followed by citric and fumaric acids (Table 4). Data for malic acid showed a statistically significant increase in carrots from the ORG system compared to INT for all tested cultivars. For pyruvic and citric acids ANOVA showed significant differences between cultivars, with the highest concentration of both acids in roots of Rodelika. Fumaric acid content differed significantly only in roots of Rodelika, in which a higher amount was found in carrots from the ORG system than the INT system.

Vitamin C detected in the study was significantly influenced by the farming system (Figure 2). Comparing farming systems in general, averaging across cultivars showed a statistically significant increase in average vitamin C content in carrots from ORG compared to carrots from the INT cultivation system.

Table 2. Morphological traits of roots for three carrot varieties grown in organic (ORG) and integrated (INT) farming systems in two growing seasons (2011–2012).

Variety	System	Root weight (g)	Root length (cm)	Diameter (mm)	Phloem/xylem ratio	Aboveground weight (g)
Fanal	ORG	140.7 ± 11.2 a	17.0 ± 0.4 a	32.4 ± 1.1 a	2.1 ± 0.1	20.6 ± 2.1 a
	INT	47.3 ± 4.3 d	13.1 ± 0.5 c	24.4 ± 0.9 c	2.2 ± 0.1	11.8 ± 1.1 c
Rodelika	ORG	68.8 ± 4.7 b	14.2 ± 0.4 b	28.7 ± 0.8 b	2.0 ± 0.1	12.0 ±1.1 c
	INT	63.6 ± 6.6 bc	13.4 ± 0.5 bc	28.9 ± 1.1 b	2.1 ±0.1	18.4 ± 2.3 ab
Rolanka	ORG	56.5 ± 3.9 cd	14.2 ± 0.4 b	26.3 ± 0.7 bc	2.1 ± 0.1	11.5 ± 1.0 c
	INT	56.2 ± 5.5 cd	14.0 ± 0.5 b	24.4 ± 1.1 c	2.1 ± 0.1	14.4 ± 1.8 bc
ANOVA Variety System Variety × system		 * * ***	 * ** ***	 *** *** ***	 * n.s. n.s.	 * * ***

Values are given as mean ± SD. Different letters in columns indicate statistically significant differences (Duncan test, $P < 0.05$) in morphological traits according to variety, farming system, or combined effect of variety × farming system. Factors or their interactions are significant at *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$; n.s. - not significant.

Table 3. Content of fructose (g kg^{-1} FW), glucose (g kg^{-1} FW), sucrose (g kg^{-1} FW), and total sugars (g kg^{-1} FW) in carrot roots of tested cultivars from organic (ORG) and integrated (INT) farming systems in two growing seasons (2011–2012).

Variety	System	Fructose (g kg^{-1})	Glucose (g kg^{-1})	Sucrose (g kg^{-1})	Total sugars (g kg^{-1})
Fanal	ORG	16.2 ± 1.7	23.3 ± 2.6	37.1 ± 5.8	76.6 ± 8.1
	INT	21.9 ± 2.7	31.3 ± 3.9	42.6 ± 5.4	95.9 ± 10.6
Rodelika	ORG	16.5 ± 2.6	24.4 ± 3.9	55.2 ± 5.2	96.1 ± 10.8
	INT	13.5 ± 2.9	21.1 ±4.4	40.9 ± 7.7	75.6 ± 13.6
Rolanka	ORG	12.7 ± 1.9	19.1 ± 2.5	49.4 ± 5.3	81.1 ± 9.0
	INT	14.8 ± 3.6	23.0 ± 5.3	58.1 ±13.5	96.3 ± 18.5
ANOVA Variety System Variety × system		 ** n.s n.s.	ilr_1 [#] * n.s. n.s.	ilr_2 [##] n.s. n.s. n.s.	 n.s n.s. n.s.

Values are given as mean ± SD. Different letters in columns indicate statistically significant differences (Duncan test, $P < 0.05$) according to variety, farming system, or combined effect of variety × farming system. Factors or their interactions are significant at ** $P < 0.01$, * $P < 0.05$; n.s. - not significant.

[#]ilr_1 - First coordinate of isometric log ratio transformation, 0.707 *ln*(fructose (%)/glucose (%)).

[##]ilr_2 - Second coordinate of isometric log ratio transformation, 0.816 *ln*(sucrose(%)/g(fructose(%) glucose (%))), g() presents geometric mean.

Two carotenoids were detected in our samples, α-carotene and β-carotene, and both were significantly affected only by variety (Figure 3). ANOVA showed a statistically significant lower content of α-carotene and β-carotene in roots of Fanal compared to Rodelika. There were no significant differences in α-and β-carotene content in carrots from the INT and ORG systems. For a more detailed analysis of the effect of cultivar and farming

Table 4. Content of malic acid (g kg^{-1} FW), pyruvic acid (g kg^{-1} FW), citric acid (g kg^{-1} FW), and fumaric acids (g kg^{-1} FW) in carrot roots of tested cultivars from organic (ORG) and integrated (INT) farming systems in two growing seasons (2011–2012).

Variety	System	Malic acid (g kg^{-1})	Pyruvic acid (g kg^{-1})	Citric acid (g kg^{-1})	Fumaric acid (g kg^{-1})	Total organic acids (g kg^{-1})
Fanal	ORG	1.9 ± 0.4 A	0.9 ± 0.0 b	0.2 ± 0.02 b	0.12 ± 0.01 c	3.18 ± 0.4 bA
	INT	1.2 ± 0.2 B	0.8 ± 0.0 b	0.1 ± 0.04 b	0.14 ± 0.01 bc	2.23 ± 0.4 bB
Rodelika	ORG	2.4 ± 0.1 A	1.0 ± 0.1 a	0.2 ± 0.02 a	0.20 ± 0.02 a	3.89 ± 0.2 abA
	INT	1.0 ± 0.3 B	1.2 ± 0.2 a	0.4 ± 0.22 a	0.13 ± 0.02 bc	2.73 ± 1.8 bB
Rolanka	ORG	2.5 ± 0.2 A	0.9 ± 0.0 b	0.2 ± 0.02 ab	0.19 ± 0.01 ab	3.85 ± 0.2 aA
	INT	1.6 ± 0.5 B	1.0 ± 0.1 b	0.2 ± 0.05 ab	0.13 ± 0.01 bc	2.91 ± 0.6 aB
ANOVA Variety System Variety × system		 n.s. ** n.s.	 * n.s. n.s.	 * n.s. n.s.	 n.s. * *	 * * n.s.

Values are given as mean ± SD. Different lower case letters in columns indicate statistically significant differences (Duncan test, $P < 0.05$) according to variety; different capital letters in columns indicate statistically significant differences according to farming system. Factors or their interactions are significant at ** $P < 0.01$, * $P < 0.05$; n.s. - not significant.

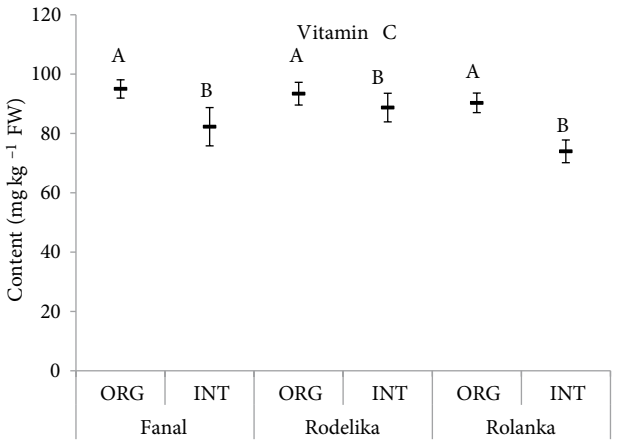

Figure 2. The average vitamin C content in selected carrot roots of three varieties (Fanal, Rodelika, and Rolanka) from organic (ORG) and integrated (INT) farming systems in two growing seasons (in 2011 and 2012). Values are shown as mean ± SD. Different capital letters denote significantly differences (Duncan test, $P < 0.05$) between farming systems (ORG and INT).

system on the structure of carotenoids, we analyzed the relationship between α- and β-carotene (β-car/α-car). A higher ratio of β-car/α-car was detected for carrots gathered from the INT system (1.9) compared to ORG systems (1.7), but the difference was not significant.

Among phenolic compounds, four phenolic acids (Table 5) belonging to the hydroxycinnamic acid group were confirmed in our samples. We identified and quantified chlorogenic acid as the major one, followed by ferulic acid derivative, 5-*p*-coumaroylquinic acid, and feruloylquinic acids as the minor phenolic acids. Ferulic acid derivative and 5-*p*-coumaroylquinic acid concentrations varied significantly in relation to cultivar, which was revealed by lower concentrations of those acids in the carrot samples of Fanal and Rodelika compared to Rolanka.

4. Discussion

In an organic system, yield is reportedly 10%–20% lower than in conventional or integrated systems (Ponisio et al., 2015). Such yield reduction is mainly due to the scarcity of genotypes adapted for this system, as well as stress-associated effects, such as pest outbreaks and nutritional imbalances, which may impact organic crops more than conventional crops (Dorais and Alsanius, 2015). Such a finding was not confirmed in our study, in which yield ranged between 42 and 44 t ha^{-1} for the ORG treatment and between 37 and 40 t ha^{-1} for the INT treatment, which was within the carrot yield range (28–61 t ha^{-1}) reported in European countries (http://ec.europa.eu/eurostat). Although yields in organic farming are usually limited by nutrient supply and diseases, it is suggested that an organic system tends to be more efficient than conventional or integrated systems, presumably as a result of enhanced microbial activity or because of a build-up of organic nutrient pools (Dimitri and Oberholtzer, 2009). Increase in carrot yield from the organic system could also be attributed to the selection of appropriate varieties

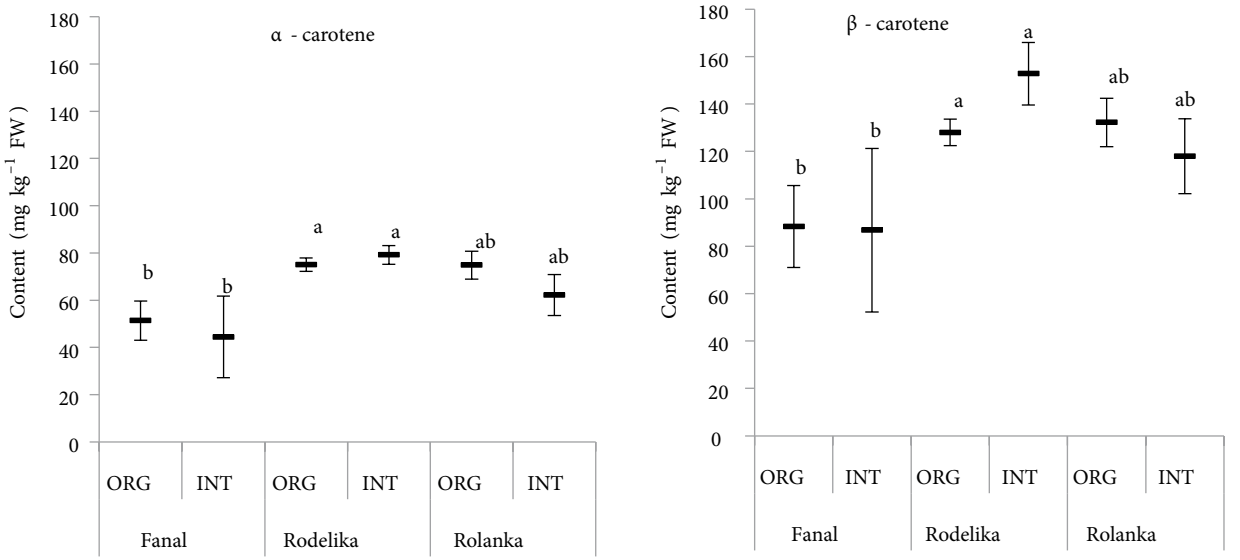

Figure 3. The average content of α-carotene and β-carotene in selected carrot roots of three varieties (Fanal, Rodelika, and Rolanka) from organic (ORG) and integrated (INT) farming systems in two growing seasons (in 2011 and 2012). Values are shown as mean ± SD.
Different letters denote significantly differences (Duncan test, $P < 0.05$) among varieties (Fanal, Rodelika, and Rolanka).

Table 5. Content of phenolic acids (mg kg^{-1}) in carrot roots for tested cultivars from organic (ORG) and integrated (INT) farming systems in two growing seasons (2011–2012).

Variety	System	Chlorogenic acid (mg kg^{-1})	Ferulic acid derivative (mg kg^{-1})	5-*p*-coumaroylquinic acid (mg kg^{-1})	Feruloylquinic acid (mg kg^{-1})	Total phenols (mg kg^{-1})
Fanal	ORG	4.4 ± 0.8	1.6 ± 0.3	1.9 ± 0.4	0.9 ± 0.2	8.8 ± 1.3
	INT	3.6 ± 1.7	1.5 ± 0.6	1.8 ± 1.0	0.7 ± 0.3	7.5 ± 3.6
Rodelika	ORG	2.9 ± 0.7	1.3 ± 0.3	1.1 ± 0.3	0.8 ± 0.2	6.1 ± 1.4
	INT	2.3 ± 1.4	1.1 ± 0.2	0.7 ± 0.2	0.5 ± 0.2	4.6 ± 1.9
Rolanka	ORG	4.7 ± 0.9	3.3 ± 0.7	1.7 ± 0.4	1.5 ± 0.4	11.2 ± 1.8
	INT	4.2 ± 1.7	2.3 ± 0.4	2.3 ± 0.7	0.8 ± 0.2	9.6 ± 2.8
ANOVA						
Variety		n.s.	*	*	n.s.	n.s.
System		n.s.	n.s.	n.s.	n.s.	n.s.
Variety × system		n.s.	n.s.	n.s.	n.s	n.s.

Values are given as mean ± SD. Different letters in columns indicate statistically significant differences (Duncan test, $P < 0.05$) in individual and total phenolic acids according to variety. Factors or their interactions are significant at * $P < 0.05$; n.s. - not significant.

(Fanal, Rodelika, and Rolanka) tested in our study, which were intended mostly for organic cultivation. It has been reported that varieties usually used in organic farming are genetically more resilient and tolerant to environmental constraints than varieties intended for conventional cultivation (Maggio, 2013; Orsini et al., 2016). On the other hand, fertilizers used in organic farming typically provide nutrients in a form less readily accessible to plants than synthetic fertilizer; therefore, they tend to act as slow-release fertilizer, providing a more regular and homogeneous supply of nutrients throughout the growing season (Gutser et al., 2005). The long history of organic management in the experimental plot could partly explain our results of higher yield in the ORG system compared to

the INT system. The increased levels of NO_3-N in plots of the organic system measured during the growing seasons and decreased levels in plots of the integrated system also confirmed the abovementioned statements (Table 1).

Changes in sugar composition may have been a result of the conversion of glucose and fructose to sucrose or the hydrolysis of sucrose to monosaccharide forms, which is usually dependent on the biochemical requirements at specific developmental stages (Krook et al., 2000). In our study, the trends in sugar content and composition followed the general patterns reported in previous studies (Rosenfeld, 1998; Karkleliene et al., 2012). At harvest, glucose and fructose levels showed a decreasing trend in taproots of Fanal and Rolanka carrots from the INT system compared to the ORG system, and the opposite results were found for taproots of Rodelika (Table 3). In addition, a significant impact of farming system on sugar composition was also determined as revealed in a higher sucrose/hexose ratio (ilr_2) for carrots from ORG plots (0.33) compared to the INT plots (0.30). This corresponds with the findings of Bavec et al. (2010), who observed a trend of higher total sugar content in roots of red beet from an organic system compared to conventional, integrated, and control (nonfertilized plots) production systems. The effect of diversified nitrogen fertilization on the chemical structure in carrots has already been evaluated by Smolen and Sady (2009). They pointed out that, in addition to nutrient application, variable soil conditions in combination with climatic conditions considerably influenced sugar concentration.

Vegetables, in general, contain low amounts of organic acids although these compounds influence the organoleptic characteristics of fruits and vegetables, mostly their flavor (Wang et al., 2008). Significantly higher values of malic acid and total organic acid were measured in carrots from the organic system in comparison to samples from the integrated system, which is partly in accordance with findings of previous studies, where higher values of malic acid were measured in organically cultivated maize and blueberries (Wang et al., 2008; Röhlig and Engel, 2009). The taste and flavor can be described by the sugar/acid ratio, which is defined as the total sugar content compared to the total acid level (Mikulic-Petkovsek et al., 2012). This index is an important measure for carrot roots, since it influences the perception of sweetness, which is an important carrot characteristic from consumer and processing industry points of view. In our study, the sugar/acid ratio differed in relation to the farming system, with a higher ratio for carrots from the INT system and lower ratio for the ORG system. The sugar/acid ratio also differed among the cultivars, with the highest ratio for the carrots of Fanal, followed by the taproots of Rodelika and Rolanka.

Although vitamin C is essential in all vegetables, carrot is not an obvious source of it. In our study, the vitamin C contents in the carrot roots ranged from 7.4 to 9.5 mg 100 g^{-1} FW, which are much higher values than those reported by Nicolle et al. (2004) and Singh et al. (2012), who ascribed the low vitamin C content in their samples to a particularly wet harvest season. The high vitamin C content in our samples might therefore also have been a consequence of relatively warm weather in 2011 and 2012, in which average temperatures exceeded the long-term average by 1.4 °C and 1.6 °C, respectively, and precipitation was nearly 20% less per year. The genotypic impact on vitamin C content in carrot root that was previously reported for dark purple, dark orange, and yellow root varieties (Nicolle et al., 2004; Singh et al., 2012) was not confirmed in our study, in which all tested varieties were orange-colored carrots. In spite of the fact that reports of the vitamin C levels in organic and conventional foods have not been consistent (Bourn and Prescott, 2002), in our study, roots of all varieties from the organic system had significantly higher levels of vitamin C than those from the integrated system (Figure 2).

Carrot storage roots are a rich source of carotenoids, which not only determine root color but also affect the perception of carrot taste and flavor, which influence consumer preference (Alasalvar et al., 2005). In our study, the carotenoid content varied among cultivars and farming systems and ranged from 9.2 to 23.2 mg/100 g FW, in accordance with results previously described in the literature (Nicolle et al., 2004; Singh et al., 2012). The main pigments of orange carrot are α- and β-carotene, which was also confirmed in our study, although their composition was not influenced by genotype, as was reported by Nicolle et al. (2004), who tested cultivars with colored roots and differences among them arose from differences in carotenoid structure.

Since cultivation methods that utilize high levels of pesticides and fertilizers can result in a disruption of the natural plant-defense metabolites, we expected higher levels of secondary metabolites in organically grown carrots than in those from the integrated farming system. Reviews of the literature have shown inconsistent differences in the nutritional quality of organically and conventionally cultivated fruits and vegetables (Bourn and Prescott, 2002), which might be a result of variations in cultivar selection and growing conditions and the methods of sampling and analysis. In our study, consistently higher levels of chlorogenic acid, detected as the major phenolic acid, in organically grown carrots compared to carrots from the INT system were found, but the differences were not statistically significant. The levels of ferulic acid derivative and 5-*p*-coumaroylquinic acid, as the second and the third prevailing acids, were influenced by variety, with higher levels of both acids in Rolanka compared to other varieties.

Smolen and Sady (2009) showed that nutrient application, regardless of the form of fertilizer (organic or mineral), caused an increase in phenolic compound levels in carrot roots compared to plants from unfertilized plots.

Our results provide the specific chemical composition and morphological traits of yield of three carrot cultivars from organic and integrated farming systems. For further analyses, mineral content levels in soil and plants could be included in the study and, with the evaluation of the nutritional status of the crops, could contribute to improved management systems as well as the biochemical profile.

Acknowledgment
This research is part of the program Horticulture No. P4-0013-0481, funded by the Slovenian Research Agency.

References

Alasalvar C, Al-Farsi M, Quantick PC, Shahidi F, Wiktorowicz R (2005). Effect of chill storage and modified atmosphere packaging (MAP) on antioxidant activity, anthocyanins, carotenoids, phenolics and sensory quality of ready-to-eat shredded orange and purple carrots. Food Chem 89: 69-76.

Bavec M, Turinek M., Grobelnik-Mlakar S, Slatnar A, Bavec F (2010). Influence of Industrial and alternative farming systems on contents of sugars, organic acids, total phenolic content, and the antioxidant activity of red beet (*Beta vulgaris* L. spp. *vulgaris* Rote Kugel). J Agr Food Chem 58: 11825-11831.

Bourn D, Prescott J (2002). A comparison of the nutritional value, sensory qualities, and food safety of organically and conventionally produced foods. Crit Rev Food Sci Nutr 42: 1-34.

Brandt K, Molgaard JP (2001). Organic agriculture: does it enhance or reduce the nutritional value of plant foods? J Sci Food Agric 81: 924-931.

Chugahuja JK, Holden JM, Forman MR, Mangels AR, Beecher GR, Lanza E (1993). The development and application of a carotenoid database for fruits, vegetables, and selected multicomponent foods. J Am Diet Assoc 93: 318-323.

Dimitri C, Oberholtzer L (2009). Meeting market demand in the organic sector: handler-supplier relationships in the face of tight supply. Renew Agr Food Syst 24: 137-145.

Dorais M, Alsanius BW (2016). Recent advances in organic horticulture technology and management. Sci Hortic 208: 1-2.

Eur-Lex (2007). Council Regulation (EC) No 834/2007 of 28 June 2007 on Organic Production and Labelling of Organic Products and Repealing Regulation (EEC) No 2092/91. Brussels, Belgium: Eur-Lex.

Eur-Lex (2014). Opinion of the European Economic and Social Committee on 'Integrated Production in the European Union' (Own-Initiative Opinion). Brussels, Belgium: Eur-Lex.

Gajewski M, Szymczak P, Bajer M (2009). The accumulation of chemical compounds in storage roots by carrots of different cultivars during vegetation period. Acta Sci Pol-Hortorum Cultus 8: 69-78.

Goncalves EM, Pinheiro J, Abreu M, Brandao TRS, Silva CLM (2010). Carrot (*Daucus carota* L.) peroxidase inactivation, phenolic content and physical changes kinetics due to blanching. J Food Eng 97: 574-581.

Gutser R, Ebertseder T, Weber A, Schraml M, Schmidthalter U (2005). Short-term and residual availability of nitrogen after long-term application of organic fertilizer on arable land. J Plant Nutr Soil Sci 168: 439-446.

Karkleliene R, Radzevicius A, Dambrauskiene E, Surviliene E, Bobinas C, Duchovskiene L, Kavaliauskaite D, Bundiniene O (2012). Root yield, quality and disease resistance of organically grown carrot (*Daucus sativus* Rohl.) hybrids and cultivars. Zemdirbyste 99: 393-398.

Krook J, Vreugdenhil D, van der Plas LHW (2000). Uptake and phosphorylation of glucose and fructose in Daucus carota cell suspensions are differently regulated. Plant Physiol Biochem 38: 603-612.

Mader P, Fliessbach A, Dubois D, Gunst L, Fried P, Niggli U (2002). Soil fertility and biodiversity in organic farming. Science 296: 1694-1697.

Maggio A, De Pascale S, Paradiso R, Barbieri G (2013). Quality and nutritional value of vegetables from organic and conventional farming. Sci Hortic 164: 532-539.

Mikulic-Petkovsek M, Schmitzer V, Slatnar A, Stampar F, Veberic R (2012). Composition of sugars, organic acids, and total phenolics in 25 wild or cultivated berry species. J Food Sci 77: C1064-C1070.

Mikulic-Petkovsek M, Stampar F, Veberic R (2007). Parameters of inner quality of the apple scab resistant and susceptible apple cultivars (*Malus domestica* Borkh.). Sci Hortic 114: 37-44.

Mizrahi A, Knekt P, Montonen J, Laaksonen MA, Heliovaara M, Jarvinen R (2009). Plant foods and the risk of cerebrovascular diseases: a potential protection of fruit consumption. Br J Nutr 102: 1075-1083.

Nicolle C, Simon G, Rock E, Amouroux P, Remesy C (2004). Genetic variability influences carotenoid, vitamin, phenolic, and mineral content in white, yellow, purple, orange, and dark-orange carrot cultivars. J Am Soc Hortic Sci 129: 523-529.

Orsini F, Maggio A, Rouphael Y, De Pascale S (2016). "Physiological quality" of organic grown vegetables. Sci Hortic 208: 131-139.

Paoletti F, Raffo A, Kristensen HL, Thorup-Kristensen K, Seljasen R, Torp T, Busscher N, Ploeger A, Kahl J (2012). Multi-method comparison of carrot quality from a conventional and three organic cropping systems with increasing levels of nutrient recycling. J Sci Food Agric 92: 2855-2869.

Pawlowsky-Glahn V, Buccianti A (2011). Compositional Data Analysis: Theory and Applications. Oxford, UK: Blackwell Science.

Phatak SC (1992). An integrated sustainable vegetable production system. HortScience 27: 738-741.

Ponisio LC, M'Gonigle LK, Mace KC, Palomino J, de Valpine P, Kremen C (2015). Diversification practices reduce organic to conventional yield gap. Proc R Soc 282: 1396.

RDC Team (2011). R: A Language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing.

Reganold JP, Wachter JM (2016). Organic agriculture in the twenty-first century. Nat Plant 2: 15221.

Reinsaat (2016). Gemüse-, Kräuter- und Blumensaatgut aus biologisch-dynamischem und organisch-biologischem Anbau. St. Leonhard am Hornerwald, Austria: Reinsaat.

Rodriguez-Amaya DB (2010). Quantitative analysis, in vitro assessment of bioavailability and antioxidant activity of food carotenoids-A review. J Food Compos Anal 23: 726-740.

Röhlig RM, Engel K (2010). Influence of the system (conventional versus organic farming) on metabolite profiles of maize (*Zea mays*) kernels. J Agric Food Chem 58: 3022-3030.

Rosen CJ, Allan DL (2007). Exploring the benefits of organic nutrient sources for crop production and soil quality. HortTechnology 17: 422-430.

Rosenfeld HJ (1998). Maturity and development of the carrot root (*Daucus carota* L.). Gartenbauwissenschaft 63: 87-94.

Singh DP, Beloy J, McInerney JK, Day L (2012). Impact of boron, calcium and genetic factors on vitamin C, carotenoids, phenolic acids, anthocyanins and antioxidant capacity of carrots (*Daucus carota* L.). Food Chem 132: 1161-1170.

Smolen S, Sady W (2009). The effect of various nitrogen fertilization and foliar nutrition regimes on the concentrations of sugars, carotenoids and phenolic compounds in carrot (*Daucus carota* L.). Sci Hortic 120: 315-324.

Soltoft M, Nielsen J, Lauren KH, Husted S, Halekoh U, Knuthsen P (2010). Effects of organic and conventional growth systems on the content of flavonoids in onions and phenolic acids in carrots and potatoes. J Agric Food Chem 58: 10323-10329.

Stange C, Fuentes P, Handford M, Pizarro L (2008). *Daucus carota* L. as a novel model to evaluate the effect of light on carotenogenic gene expression. Biol Res 41: 289-301.

Suojala T (2000). Variation in sugar content and composition of carrot storage roots at harvest and during storage. Sci Hortic 85: 1-19.

Taylor M, Ramsay G (2005). Carotenoid biosynthesis in plant storage organs: recent advances and prospects for improving plant food quality. Physiol Plant 124: 143-151.

Wang GL, Sun S, Xing GM, Wu XJ, Wang F, Xiong AS (2015). Morphological characteristics, anatomical structure, and gene expression: novel insights into cytokinin accumulation during carrot growth and development. PLoS One 10: e0134166.

Wang SY, Chen C, Sciarappa A, Wang CA, Camp MJ (2008). Fruit quality, antioxidant capacity, and flavonoid content of organically and conventionally grown blueberries. J Agric Food Chem 56: 5788-5794.

Wright KP, Kader AA (1997). Effect of controlled-atmosphere storage on the quality and carotenoid content of sliced persimmons and peaches. Postharvest Biol Technol 10: 89-97.

Zhang DL, Hamauzu Y (2004). Phenolic compounds and their antioxidant properties in different tissues of carrots (*Daucus carota* L.). J Food Agric Environ 2: 95-100.